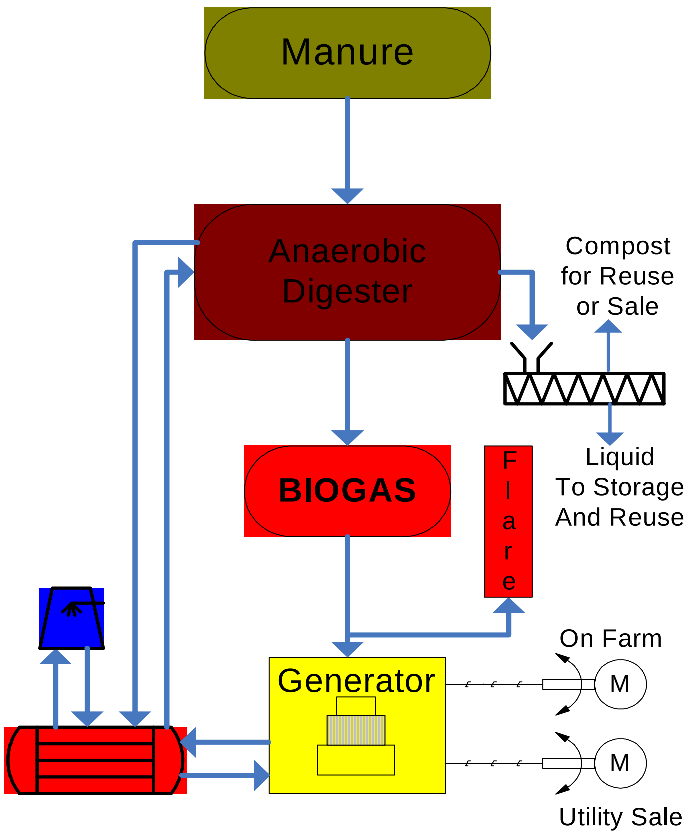
Agricultural Anaerobic Digestion

General Overview

General Process

- Natural biological (bacterial) process that primarily converts organic carbon from large molecules (carbohydrates, sugars, fats and proteins) to simple molecules (carbon dioxide, methane and water
- The primary advantages are
  - Energy recovery
  - Reduced greenhouse gas emissions
  - Odor mitigation
  - Proactive nutrient management.

Manure Digestion



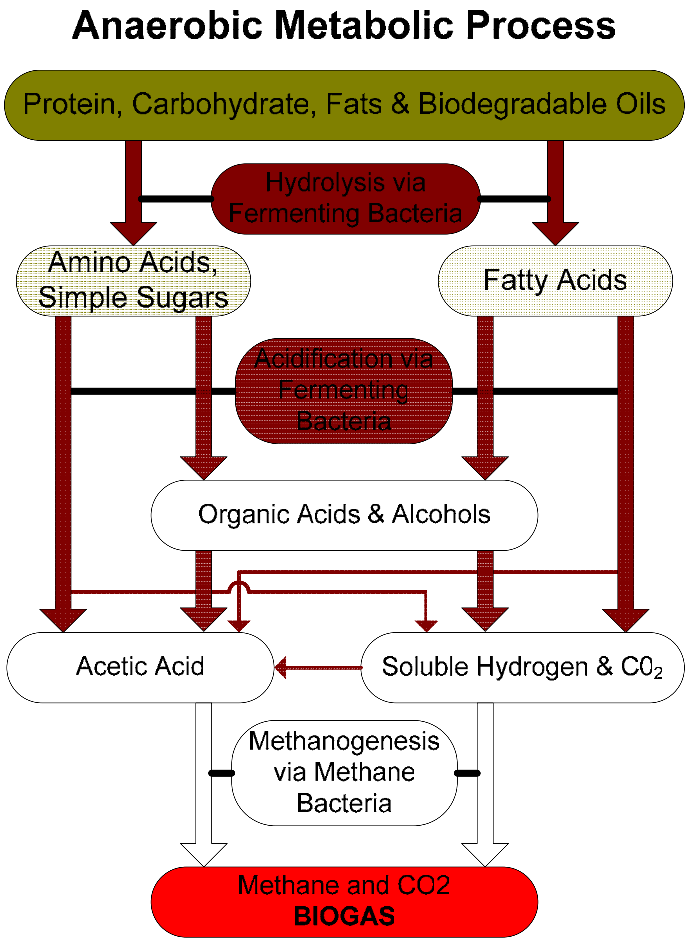
General Economics

- The net economics of applying AD varies dramatically based on
  - geography
  - facility size
  - electrical rates and usage
  - utility cooperation with buy-back programs

General Co-Digestion Concept

- Co-Digestion is being defined as an operation where non-farm organic sources are blended with those from the farm
- The primary advantages are;
  - Production of greater quantities of methane for increased energy recovery and revenue
  - Tipping fees for hauling, processing and disposal

General Metabolic Process



General Metabolic Considerations

- Like all biological processes, temperature impacts the rate of both metabolic steps.
- The vast majority of AD systems operate at or near 95-105 degrees F (mesophilic).
- Some systems utilize temperature ranges at or above 125 degrees F (Thermophilic).
- Experience has shown that mesophilic digesters are most desirable due their overall stability and ease of operation.
- It is important to note that all systems can be inhibited by indiscriminant use of persistent antimicrobial agents.

Common Approaches - On Farm Manure Handling and Digestion

- Open Lagoon
- Membrane Covered Lagoon
- Heated and Mixed Membrane Covered Lagoon
- Plug Flow Digester
- Complete Mix and Hybrid Digesters
- Fixed Film Digester
- Upright Cylinder Digester

Manure Nature and Handling

- Efficient and appropriate manure handling at the front and back is crucial to the overall success of any on-farm digestion system.
- The considerations that must be evaluated include:
  - Bedding (Straw, wood chips, sand, compost)
  - Bedding Material Recovery
  - Scrape and flush
  - Flush
  - Vacuum collection
- Each containment, digestion and management approach can be severely impacted if the manure is not properly conditioned prior to entering the system. In general the least impact is caused by compost bedding and the greatest negative impact is caused by sand bedding. A complete analysis of the overall costs involved in managing each material is imperative to financial and operational success.

Manure Handling Impacts

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Open Lagoon

- Open lagoons and pits have been the prevalent approach for holding and managing manure since farms began processing and containing the animals in large enough quantities that substantial manure volumes required containment.
- Open lagoons and pits are rapidly being eliminated due to odor and insect nuisance issues.
- Lined open lagoons are still used where neighbors or urban development are not an issue.
- These require large land areas but if land is low cost, are the lowest initial cost systems and require little or no operation other than final disposal

Membrane Covered Lagoon

- Membrane covered lagoons are rapidly appearing as the low cost method of choice to mitigate odors and insect issues.
- Most are designed to contain the off gases so that they can either be burned in a flare to eliminate odors or often, the gas is fully utilized for energy and heat recovery.
- Similar to open lagoons, these require large land areas but again, if land is low cost, they are generally the next lowest cost systems and require little or no operation attention other than final disposal.
- Several liner/cover system vendors are available with high quality and reliable equipment.

Heated and Mixed Covered Lagoon

- This modification is the next step for a lagoon and can be quite cost effective.
- The capital and operations cost of the insulated cover is substantially higher than a simple cover but the lagoon size drops substantially and energy recovery can be very good.
- Limited vendors have successful systems available.

Plug Flow Digestion

- The plug flow (PF) digester is the next step down in size requirement and generally represents a substantial increase in capital and operations effort.
- A PF digester functions like its name in that the manure is kept viscous enough to pass as a “plug” through the vessel.
- PF digesters are typically sized for a 20 day holding time and can achieve reasonable volatile solids reduction and biogas production.
- Numerous designs have been developed and many have either failed or have been abandoned due to operational issues or net economics.
- Several successful systems are in operation and are currently being designed and built as well.

Plug Flow Digestion

- The most common systems typically have biogas supported membrane covers that resemble air structures used for sport facility enclosures.
- Fixed covers have been used but have experienced many more operational challenges than floating covers.
- A PF digester *must* be heated in order to accomplish methane production. The most common heating system consists of internal hot water piping placed along the bottom outside edges.
- These pipes are most commonly schedule 40 uncoated carbon steel. A properly operating digester is a non corrosive environment and these pipes have been found to last many years.
- PF digesters must be cleaned periodically due to the buildup of materials that restrict volume and efficiency. Typical times between cleanings average about 10 years. It is common to find as much as 40% of the digester rendered ineffective in this time.
- The symptoms of plugging are reduced volatile solids reduction and biogas production. Particular care relative to operations and reference checking should be exercised prior to system selection.

Complete Mix Digester

- Complete mix digesters are typically designed with similar material holding times to plug flow digesters and generally consist of a covered bolted steel vessel with external pumps and heating equipment.
- The term complete mix implies that the contents are continuously mixed and heated.
  - This may or may not be true as it has often been found that the continuous mechanical operation leads to significantly increased maintenance and operations costs.
  - These are often operated intermittently with reasonable success.
  - Complete mix digesters have often been chosen for their smaller footprint, cleaner overall design, easier management and somewhat improved gas production from plug flow and lagoons.
- Generally, both capital and operations costs are higher than plug flow or lagoons. Like plug flow systems, there are several variations/modifications to the complete mix approach. The variations (hybrids) typically incorporate techniques or technological approaches that are very similar to classic wastewater treatment processes. These generally involve some form of solids concentration step that is either mechanical (DAF) or gravity based (clarifier). Prior to selection, check for sound design and preferably operations experience with the type of bedding system being planned or used. When operated in the sequencing batch reactor (SBR) mode, batch feeding is utilized and mixing is intermittent. Biogas production is highly variable with SBR designs which lead to unique energy recovery challenges.

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Fixed Film Digester

- This type of digester uses a vessel similar to the complete mix system but contains plastic media over which the manure is spread and allowed to trickle down to the bottom.
- Fixed film designs require very dilute well screened material to prevent plugging and are generally only considered when flushed manure management is used. With proper screening and separation nearly any bedding material can precede a fixed film system.
- There is limited experience with this approach but much research has indicated that a sound design is possible.
- Capital costs are generally higher than plug flow and similar to complete mix but excellent volatile reduction and gas production have been achieved.

Upright Cylinder Digester

- Upright cylinder digesters (UCD) use a small diameter, tall design much like the classic silage storage silo commonly seen on farms.
- This design has been shown to achieve very good volatile solids reductions at about 1/4th the detention time of plug flow or complete mix systems.
- The reason for this focuses on the physical and hydraulic contact achieved with a long column of material through which all new material must pass. Also, solids accumulation and proactive mixing at the top and bottom of the UCD allow much more intimate contact with high solids (high bacterial concentration) than plug flow or complete mix systems.

Upright Cylinder Digester

- UCD can be designed in a much more modular approach than other designs requiring large vessels and long holding times.
- The combination of modularity, small footprint, shorter holding times and mechanical simplicity all may lead to improved initial and long term economic advantages for the UCD design as more are implemented.
- This design is compatible with all but high volume flush systems common to sand bedding operations.
- When applied properly, the UCD design has been shown to provide a number of capital and operations advantages to classic designs.
- This design is also very compatible with co-digestion of offsite organics due to the continuous feeding and recirculation allowing efficient blending and microbial exposure

What is Biogas?

- Methanogenic metabolism produces essentially equal quantities of methane (CH_4) and carbon dioxide (CO_2).
- However, biogas in nearly all manure digesters will typically be 65% CH_4 and 35% CO_2.
- This variance is due solely to the high solubility of CO_2 and low solubility of CH_4.
- A point to note is that this characteristic also explains why landfill biogas has a lower BTU content and is nearly always close to the 50-50 ratio as there is no water for the CO_2 to dissolve into.
- Biogas energy value or BTU content is directly proportional to the % CH_4. Pure CH_4 has a BTU level of approximately 1000 BTU's per cubic foot so the BTU content of biogas is linearly reduced by the percentage, leaving a common content of about 650 BTU's per cubic foot. Any variations claimed by a system provider will be strictly associated with the dilution. In this regard, flushed manure systems will generally produce higher BTU gas due to the CO_2 being dissolved in the higher volume of water. Though the biogas is higher in BTU's flush systems must consume more onsite energy to heat all that water for digestion and thus there is generally a negative net energy benefit.
- Hydrogen sulfide (H_2S) is the other trace gas commonly present in manure biogases and is the one responsible for nearly all the negative press. It may range from 0.2% to over 1%. Bovine manure will generally be just above 0.2% while porcine manure is generally at or above 0.5%. H_2S solubility, like CH_4 is relatively low. This characteristic explains why containing any manure in either a covered lagoon or vessel and combusting the biogas resolves most odor issues. When adequately contained and ventilated, digester effluent releases most of the sulfur in the biogas and thus is more neighbor friendly when exposed in either open storage vessels or when land applied. The odor is eliminated because the H_2S is converted to SO_2 when combusted in a flare or generator.
- Unfortunately, sulfur emissions can become an issue in large systems and must be carefully considered in any biogas utilization plan. The issues will range from system design to equipment selection and air quality permitting. The most common solution when sulfur emissions must be reduced is an iron sponge scrubber. The iron in the sponge (wood particles) reacts with the sulfur to yield iron sulfide. The sponge may be regenerated and/or disposed as a soil amendment. Some care is required depending on the scrubber design and operation.

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Biogas Utilization

- In general, biogas utilization is accomplished with one or more of the following steps whose order in the process will depend on the system:
  - Collection piping
  - Moisture and sediment control
  - Pressure management and control
  - Hydrogen Sulfide management and control
  - Utilization rate and/or storage
  - Combustion and energy utilization

Energy Recovery

- Regardless of the circumstances, some of the factors that must be considered when energy recovery is involved are:
  - Energy equipment capital and operations costs.
  - Local electrical energy costs.
  - Onsite electrical and heat usage that will be offset.
  - Cooling requirements for adsorption chilling options.
  - Air emissions restrictions for combusting biogas.
  - Utility energy buy-back program opportunities or obstacles.

The Community Digester Concept

- As knowledge and experience with agricultural manure digesters have grown, it has become readily apparent that many designs are capable of accommodating fairly substantial quantities of outside biodegradable organic materials.
- The two general benefits to this practice are
  - increased biogas production which translates to greater energy recovery
  - tipping or hauling fees which can often be collected from the entity generating the organic material.

The Community Digester Concept

- Almost without exception, the organics are coming from a food production facility.
- The following industries commonly have the need to dispose of high strength organics either onsite or via offsite disposal or land application systems:
  - All aspects of dairy processing, including ice cream, cheese, yogurt, sour cream, milk condensing and bottling.
  - Brewing and beverages of all types, (beer, distilled spirits, wine, juice, soda).
  - Neutraceutical Production (Nutrient Drinks such as Slim Fast, Ensure).
  - Fruit and Vegetable processing.
  - Prepared foods production, frozen meals to salad dressing.

Implementation - Concept

- Conceptual Review – This first step could also be termed the litmus test in that some very basic issues are tabulated and given a general analysis relative to need, cost and value. The basic questions that should be asked and answered are:
  - Is manure handling either an insect or an odor problem?
  - Are electrical costs either high or burdensome?
  - Is there a reasonable utility energy buy-back program?
  - Are there grants, rebates or low interest loans available?
  - Is there any pending or encroaching land zoning/use limitation?
  - Questions 1 & 2 are deal breakers in many cases in that a project to contain the manure may be required to remain operational at the current location. At this point, the incremental costs of capturing and utilizing the biogas are often very attractive.
  - of economic objectives.

Implementation - Economics

- Macro Economics – If a full scale energy project appears to have some financial feasibility after initial evaluation, a macro economic assessment should be completed. This should be accomplished with the guidance of an experienced company or individual. The evaluation should include an initial manure handling and digestion process assessment along with general capital, operations costs along with the value of potential rebates, energy savings and sales.
- Detailed System Economics and Financing – If the macro economic assessment indicates an attractive return on investment, then a complete system analysis and selection process should be completed. This step is often referred to as a Design Memorandum where every process is sized, layouts proposed and all equipment is quantified. A detailed capital, operations and benefit analysis is completed at this point. Work through this step is generally required to receive funding commitments for either loans, grants or rebates. In general, successful and sustainable projects should be financially attractive with no grants or rebates and only enhanced by their availability.

Implementation – Design and Construction

- Design – Using the design memorandum as the guiding document, the system will then proceed to formal design where professional engineers are retained to properly develop plans and specifications for construction. This process can be expected to take 4-6 months for most digesters and longer for large and/or more complicated systems.
- Construction – This step may take several contract forms depending on the owner's level of sophistication and the system's size. The project can range from a turnkey design build to classic bidding and general contracting. Much will depend on the system selected and capability of the related vendors and/or contractors. Again, depending on the owner and the project size and complexity, 4-8 months may be required for construction.

Implementation - Sustainability

- Operations and Maintenance – Most successful systems have been so due to overall simplicity and relatively low operations and maintenance costs. This should be clear during the macro economic evaluation stage where complex systems can be ruled out if there are no net economical advantages. It should be considered critical for most operations that O&M be simple and reliable.
- Sustainability – The sustainability of a project should be well determined prior to selection and design so that after startup, the system becomes the process and economic combination that was anticipated. The items that will affect sustainability are:
  - Thorough and proper process selection
  - Process reliability
  - Quality of design and process equipment
  - Quality and commitment of owner and operations & maintenance staff
  - Attainment of economic objectives

Summary

- **Overview** – Determining the feasibility of using agricultural AD is fairly complex but attaining a reasonable level of success is achievable if systematically approached
- **Metabolism** – Anaerobic metabolism within an anaerobic digester is a very robust process that when properly managed can yield many benefits to an agricultural operation.
- **Systems** – A modern agricultural AD operation is comprised of several integral processes or systems.
- **Designs** – Many AD designs have been developed. Each design has specific characteristics that when optimized will lead to a successful installation and operation.
- **Co-Digestion** – The concept of co-digestion is a fairly recent development in agricultural AD systems.
- **Energy & Economics** – Interest in agricultural AD systems is usually initiated by the energy value realized when CH_4 is produced and utilized. In addition to energy however is the growing factor of odor control. In many locations animal operations can not continue without minimizing the normal odors associated with animal manure.
- **Implementation** – A successful AD project demands that a systematic approach be followed. The steps include preliminary evaluations, macro economic analysis, micro economic analysis, financing plans and design memos, system design, construction, startup and sustainable operations plans. Failure to follow the systematic approach greatly increases the chance for financial disappointment or complete system failure. On the other hand, following a systematic approach generally leads to proper system selection and success.

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